Stroke phases responses around maximal lactate steady state in front crawl

Jailton G. Pelarigo, Benedito S. Denadai*, Camila C. Greco

Human Performance Laboratory, UNESP, Rio Claro, Brazil

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Abstract

The objective of this study was to analyze changes in stroke rate (SR), stroke length (SL) and stroke phases (entry and catch, pull, push and recovery) when swimming at (MLSS) and above (102.5% MLSS) the maximal lactate steady state. Twelve endurance swimmers (21 ± 8 year, 1.77 ± 0.10 m and 71.6 ± 7.7 kg) performed in different days the following tests: (1) 200- and 400-m all-out tests, to determine critical speed (CS), and; (2) 2–4 30-min sub-maximal constant-speed tests, to determine the MLSS and 102.5% MLSS. There was significant difference among MLSS (1.22 ± 0.05 m s⁻¹), 102.5% MLSS (1.25 ± 0.04 m s⁻¹) and CS (1.30 ± 0.08 m s⁻¹). SR and SL were maintained between the 10th and 30th minute of the test swum at MLSS and have modified significantly at 102.5% MLSS (SR – 30.9 ± 3.4 and 32.2 ± 3.5 cycles min⁻¹ and SL – 2.47 ± 0.2 and 2.38 ± 0.2 m cycle⁻¹, respectively). All stroke phases were maintained at 10th and 30th minute at MLSS. However, the relative duration of propulsive phase B (pull) increased significantly at 102.5% MLSS (21.7 ± 3.4% and 22.9 ± 3.9%, respectively). Therefore, the metabolic condition may influence the stroke parameters (SR and SL) and stroke strategy to maintain the speed during swim tests lasting 30 min.

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1. Introduction

In swimming, both biomechanical (i.e., the level of application of propulsive force and passive and active drag) and physiological aspects (i.e., the energy production systems) are essential to the locomotion and significantly contribute to performance.¹ The swimming technique has been frequently assessed using both stroking parameters (stroke rate – SR and stroke length – SL) and the index of coordination (IdC). The IdC represents how the swimmers organize the propulsive (pull and push) and non-propulsive (glide + catch and recovery) phases of right and left arms.² Some factors which may interfere on the stroking parameters and arm coordination are speed, swimming ability and fatigue.²,³

It has been demonstrated reduction in SL and increase in SR during all-out and imposed swim paces,³⁻⁵ which may result from the reduced capacity to generate force to overcome drag.⁶ Toussaint et al.,⁷ have analyzed the speed, SR, SL and power output (MAD system) during two maximal 100-m front crawl races. The authors found that the reduction (24%) in power-generating capacity (i.e., fatigue) led to a 12.4% decrease in speed. In addition, SR declined throughout the race (10.6%) and was related with the decrease in swim speed. As the reduction in swimming speed leads to a reduction in drag, the authors proposed that the SR adjusts to the reduced propulsion requirements.

During imposed paced, the swimmer can increase the time relative to the whole stroke cycle over which forces are applied to obtain the propulsive impulse necessary to maintain the speed, as fatigue develops.⁸ Indeed, Alberty et al.³ have demonstrated that the duration of non-propulsive phases decreased, whereas the duration of the propulsive phases remained constant during imposed swim speed tests until exhaustion. Since the SR and IdC were higher, the contribution of propulsive phases to propulsion per distance unit was increased. It is important to note that these data were obtained at 95, 100 and 110% of the mean speed attained in a 400-m race ($400), where no blood lactate steady state is observed.⁹,¹⁰

Some authors have found significant changes in SR and SL only when swimming above the anaerobic threshold¹¹...
and maximal lactate steady state (MLSS). These findings led the authors to suggest a possible relationship between the development of peripheral fatigue and the degradation in swimming technique. To the best of our knowledge, there is no data referring to the stroke strategies to maintain the speed during long-distance swims performed at conditions of metabolic equilibrium (at or below MLSS). These conditions are found during some swim training sessions and long-distance events (open water swims and long-distance triathlons) and are important to promote specific adaptations (i.e., oxidative capacity) related to long duration performance.

This study has been designed in an attempt to analyze changes in stroke parameters (i.e., SL and SR) and arm coordination (i.e., propulsive and non-propulsive phases and IdC) when swimming at (blood lactate steady state) and above (non blood lactate steady state) MLSS. Based on previous findings, it was hypothesized that (a) there would be reduction of SL and increase of SR when swimming above MLSS, and (b) these changes would be concomitant with an increase in the relative duration of propulsive phases (pull and push) and IdC.

2. Methods

Twelve middle-distance and long-distance male swimmers (mean ± SD: 21 ± 8 year, 1.77 ± 0.10 m and 71.6 ± 7.7 kg) volunteered and gave written informed consent to participate in the present study, which was approved by the university’s ethics committee. Participants were undergoing training for at least 5 years (8 training sessions a week; 50 km per week during the 2 weeks prior testing), and were competing at regional and national level (400-m performance equal to 289 s, corresponding to 74.1 ± 2.5% word record). The participants were instructed to refrain from intense training sessions at least 24 h to to minimize the effect of circadian variation on performance.

The tests were performed in a 25-m outdoor swimming-pool (26 °C). All tests were swum in front crawl, initiated with a push start. They were all conducted within a 14-day period. Testing occurred at the same time of the day (±2 h) to minimize the effect of circadian variation on performance.

Swimmers firstly performed two all-out tests at the distances of 200 (S200) and 400 m (S400), for the determination of critical speed (CS). Participants swam one event per day in random order. CS was determined using the slope of the linear regression between swimming distances and the time taken to swim.

Then, all swimmers performed 2–4 30-min sub-maximal tests at imposed pace (one test per day) for the determination of MLSS and 102.5% MLSS. The swimming speed was controlled using an mp3 player attached to the goggles of the swimmer. A regular audible signal gave the target pace to the swimmer. Four red marks were placed every 5 m at the bottom of the pool. The swimmers were instructed to keep their feet above the red marks at each signal. The difference between predict and actual swim speed was lower than 2% in all tests. Based on the results of Dekerle et al., the first trial was performed at 88.5% S400. If during the first trial a steady state or a decrease in lactate was observed, further subsequent trials with 2.5% higher speeds was performed on separate days until no blood lactate concentration ([La]) steady state could be maintained. If the first trial resulted in a clearly identifiable increase of the [La] and/or could not be completed due to exhaustion, further trials were conducted with subsequently reduced speeds. Earlobe capillary blood samples (25 μL) were collected in capillary tubes at the 10th and the 30th minute of each test, and subsequently analyzed for capillary blood [La] using an automated analyzer (YSI 2300, Yellow Springs, OH, USA). Blood samples collection lasted 30 s. MLSS was defined as the highest [La] that increased by no more than 1 mmol L⁻¹ between the 10th and 30th minute of the sub-maximal test, and were calculated as the average of the two [La] values.

The swimmers were filmed during all tests by two cameras with rapid shutter speed (1/1000s); one above the surface of the water (Panasonic – NV-GS 180, operating at 30 Hz) and one below (Panasonic – NV-GS 320, operating at 30 Hz and contained in a waterproof box). They were fixed on a trolley and pushed by an operator. This apparatus allows the analysis of each stroke cycle in a sagittal plane. Views of both cameras were postsynchronized with a visual signal that was visible on recordings for both cameras. The camera above the water measured the time over a distance of 12.5 m (from 10 m to 22.5 m) to obtain the average velocity and SR, from which SL was calculated. The reference to register the time was the swimmer’s head. The determination of stroke phases was conducted by an expertise operator (i.e., more than 30 h of experience with images analysis). Diveow software was used for the video analysis of each stroke with an accuracy of 0.017 s.

Arm coordination was quantified using the IdC defined by Chollet et al. Each arm movement was divided into four distinct phases (one phase corresponded to an action between two times), defined as phases A (glide + catch), B (pull), C (push) and D (recovery). The duration of each phase was determined as proposed by Chollet et al. and expressed as a percentage of the duration of a complete stroke. The duration of a complete stroke was the sum of the propulsive (B and C) and non-propulsive phases (A and D). The lag time between the beginning of propulsion in the first right arm stroke and the end of propulsion in the first left arm stroke defined IdC1 (i.e., arm coordination to the left side), which was expressed as a percentage of the duration of a complete stroke. The lag time between the beginning of propulsion in the second left arm stroke and the end of propulsion in the first right arm stroke defined IdC2 (i.e., arm coordination to the right side), which was also expressed as a percentage of the duration of a complete stroke. IdC was thus the mean of IdC1 + IdC2. The arm coordination was classified as “catch-up”, if the IdC
value was lower than 0, “opposition” if the value was equal to 0 and “superposition” if the value was higher than 0.²

The values were expressed as mean ± SD. For each set of data, normal distribution (Shapiro–Wilk test) and homogeneity of variance were checked. A 2-way ANOVA with repeated measures (Bonferroni correction post hoc test using the Greenhouse-Geisser procedure) was used to determine the effect of exercise intensity (at and above MLSS) and time (minutes 10 vs. 30) on SL and SR. The changes in the stroking phases and IdC over the constant-speed tests were compared using the Wilcoxon test. A significance level of 5% was accepted (p ≤ 0.05).

3. Results

The values of S200 and S400 were 1.45 ± 0.05 m s⁻¹ and 1.37 ± 0.05 m s⁻¹, respectively. There was significant difference among MLSS (1.22 ± 0.05 m s⁻¹, 88.6 ± 1.1% S400) and 102.5% MLSS (1.25 ± 0.04 m s⁻¹, 91.3 ± 1.1% S400) (p = 0.002), MLSS and CS (1.30 ± 0.08 m s⁻¹, 93.7 ± 2.7% S400) (p = 0.007) and 102.5% MLSS and CS (p = 0.028). The [La] at MLSS (3.28 ± 0.97 mmol L⁻¹) was significantly lower than at 102.5% MLSS (4.59 ± 1.36 mmol L⁻¹) (p = 0.001).

SR was maintained between the 10th and 30th minute of the test swum at MLSS (p = 0.068) and increased significantly at 102.5% MLSS (p = 0.015). Similarly, SL was maintained (p = 0.107) between the 10th and 30th minute of the test swum at MLSS and decreased significantly at 102.5% MLSS (p = 0.038). There was no significant difference on SR and SL at 10th (p = 0.898 and p = 0.736, respectively) and 30th min (p = 0.477 and p = 0.977, respectively) between two exercise intensities (Fig. 1).

Stroke phases A (p = 0.313), B (p = 0.075), C (p = 0.952) and D (p = 0.374) were maintained at 10th and 30th minute at MLSS. However, phase B increased significantly at 102.5% MLSS (p = 0.035), while the phases A (p = 0.233), C (p = 0.674) and D (p = 0.400) were maintained (Table 1).

There was no significant effect of time on IdC values at MLSS (−4.68 ± 6.6% and −3.84 ± 6.2%) and above MLSS (−3.85 ± 6.2% and −3.15 ± 6.1%). In all conditions, the arm coordination adopted was catch-up.

4. Discussion

The main findings of this study were that: (a) the SL decreased and the relative duration of pull phase increased throughout the exercise when swimming above (102.5%) MLSS, and; (b) the IdC and non-propulsive phases were not modified throughout the time, irrespectively of the swim speed analyzed. Thus, when swimming at heavy intensity domain (i.e., below CS – intensities where the steady state in VO₂ is delayed, and an additional slow component of VO₂ causes an eventual and elevated steady state),¹⁰ the metabolic condition may influence the stroke technique to maintain the speed during swim tests lasting 30 min.

Studies analyzing all-out distance trials³,⁶ and imposed pace⁹,¹¹ have found reduction in SL and increase in SR, which may result from the reduced capacity to generate force to overcome drag.⁶ Similar to our study, some authors have observed that the condition of [La] stability may be important for the maintenance of the stroke parameters during
sub-maximal imposed pace tests lasting 30 min. Dekerle et al.9 reported stability in SL (from 2.55 to 2.46 m cycles⁻¹) at MLSS throughout time for all athletes, but a reduction in SL above MLSS for the athletes who could not maintain the pace up to 30 min (from 2.76 to 2.39 m cycles⁻¹). In the former study, the athletes had similar aerobic performance level (MLSS = 1.22 m s⁻¹; S400 = 1.37 m s⁻¹) of the swimmers used in the present study. Otherwise, in a recent study conducted in our laboratory16 with less experienced athletes (MLSS = 1.13 m s⁻¹; S400 = 1.30 m s⁻¹), SL was reduced throughout the exercise at and above MLSS (102.5%), with an interaction effect between intensity and time (greater decrease at 102.5% MLSS). Differences in technical skill of the swimmers analyzed in these studies can explain the different results. In fact, some studies have verified at conditions of all-out distance trials at supramaximal intensities, that swimmers with higher technical skill would be able to maintain greater SL for longer.17,18 Therefore, at least for more experienced swimmers, MLSS represents an upper limit for maintenance of technical and physiological responses during tests lasting 30-min.

The effect of fatigue on the stroke phases and arm coordination has been analyzed during all-out distance trials4 and imposed pace.3 Alberty et al.4 analyzing all-out 200-m swim trials have verified increase of the relative duration of the propulsive phases B and C. Since SR decreased, the longer pull and push phases found in this study3 suggest that the swimmers spent more time in propulsive phases under fatigue, meaning that their capacity to generate propulsive force was compromised. Analyzing swim conditions of imposed pace and lower exercise intensity performed until exhaustion (95% and 100% S400), Alberty et al.3 verified decrease in the duration of non-propulsive phases and maintenance of the propulsive phases, with fatigue development. Since in the study conducted by Alberty et al.,3 the SR and IdC were higher, the time allotted to propulsion per distance unit was increased. Although the conditions analyzed in both studies3,4 were different (all-out or imposed pace), it can be verified that the fatigue determines an increase in the participation of the propulsive phases aiming to maintain the propulsive impulse.

In the present study, the exercise intensity (MLSS vs. 102.5%MLSS) and, consequently, the metabolic condition, were important to determine different responses only in one propulsive phase. The values of non-propulsive phases and IdC were not modified, irrespectively of the swim intensity analyzed. Therefore, the maintenance (as observed in our study) or not of the non-propulsive phases and IdC (as observed by Alberty et al.) during imposed pace cannot be explained only by the metabolic condition, but mainly by the differences of exercise intensity between studies. It is important to note that in swimming the relationship between energetic cost and speed is not linear,19 and therefore, a small increment in the speed requires a much greater metabolic energy turnover, meaning that their capacity to generate propulsive force was compromised. Analyzing swim conditions of all-out distance trials4 were different (all-out or imposed pace), it can be verified that the fatigue determines an increase in the participation of the propulsive phases aiming to maintain the propulsive impulse.

### 5. Conclusion

The changes in swimming technique (i.e., reduction in SL and increase in SR and relative duration of pull phase) of well trained swimmers during long-distance imposed speed tests performed at heavy intensity domain, occurs only at condition of non-metabolic equilibrium. Therefore, MLSS seems to determine the upper boundary beyond which an increase in the relative duration of pull phase is necessary to maintain the swim speed for a long period of time.

### 6. Practical implications

- For well trained swimmers performing continuous training sessions, the MLSS seems to be the optimal swimming technique speed.
- Different spatio-temporal and arm coordination modifications in the crawl-stroke cycle can be found at the same exercise intensity domain.
- The control of stroke phases and arm coordination during long-distance swims may add important information regarding stroke strategy.
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